Observational Evidence for Trends and Variability in the Hadley Cell Based on 15 Years of Scatterometer Ocean Surface Wind Estimates

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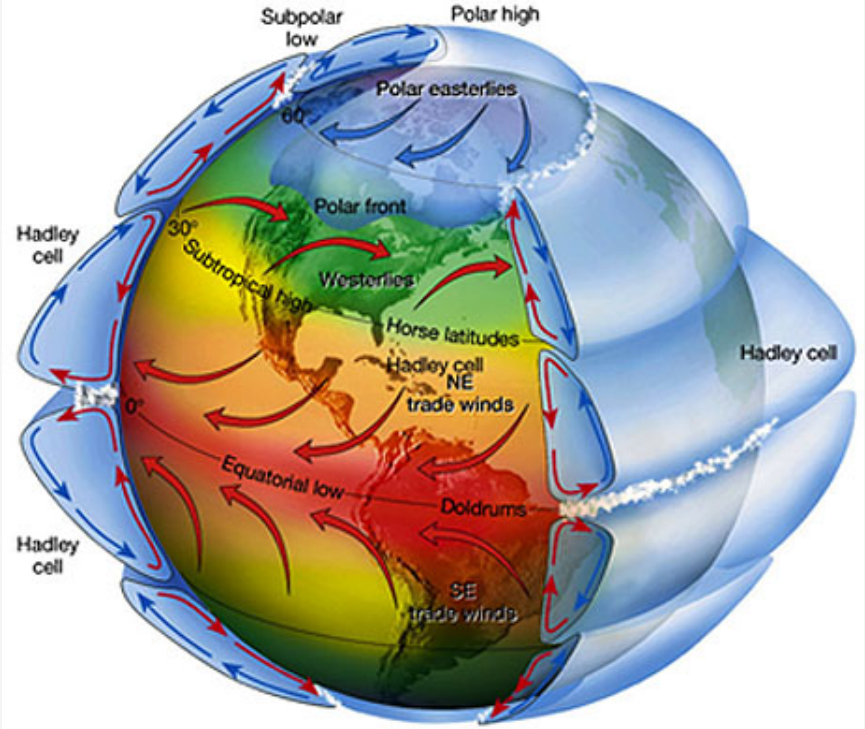
The Global Circulation and the Hadley Cell

Originally uploaded in EarthLabs:Hurricanes.

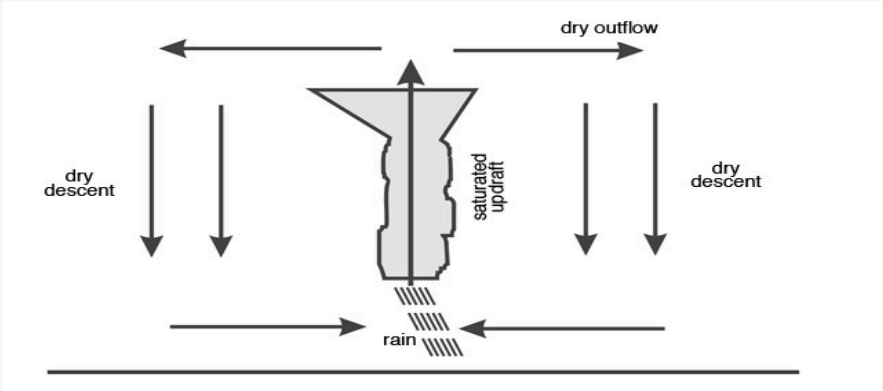


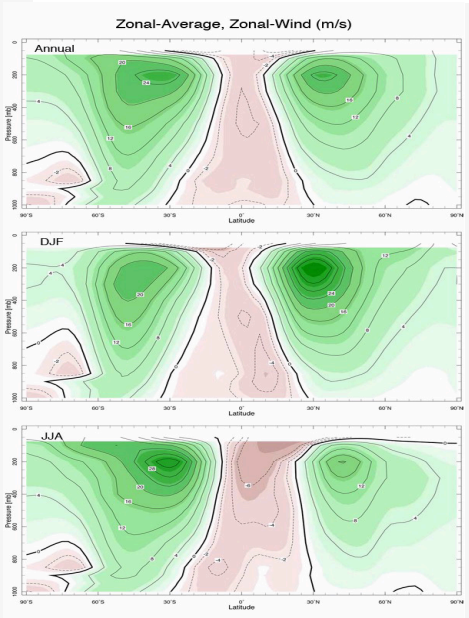
3D view of the global wind circulation due to unequal heating at the equator and the poles.

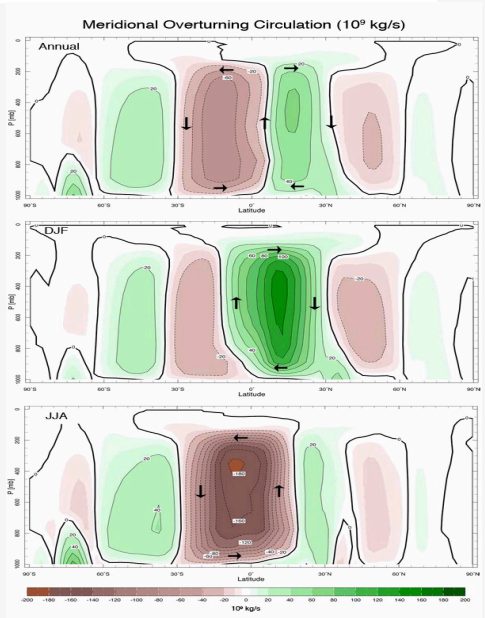
The Hadley cell depicts the equator-to-pole heat exchange in the tropical atmosphere.

Relatively simple overturning circulation, with

- rising motion near the equator
- poleward motion near the tropopause
- sinking motion in the subtropics, and
- an equatorward return flow near the surface







Motivation

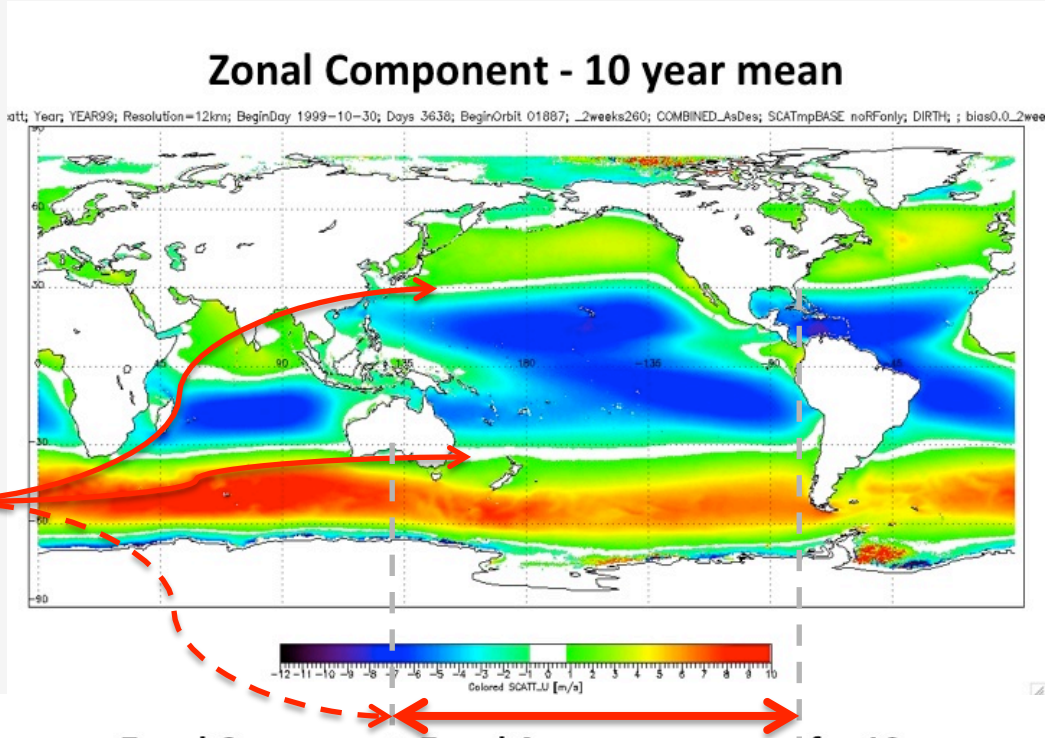
- Recent evidence suggests that **the tropics have expanded over the last few decades by a very rough 1 degree per decade.**
- This is considered to be **an atmospheric response to the observed tropical ocean warming trend** (e.g. Quan et al., 2004).
- If continued, the expansion of the tropics (the Hadley cell) could have a substantial impact on water resources and the ecology of the sub-tropics.
- **Until now, the understanding of the mechanisms that govern the changing width of the tropics has been confined to models and proxies (e.g. Johanson and Fu, 2009; Hu and Fu 2007 (OLR); Lu et al. 2007 (precipitation /evaporation estimates) because of the unavailability of systematic observations of the large-scale circulation.**
- Ocean surface vector winds, derived from scatterometer observations, provide for the first time an accurate **depiction of the large-scale circulation and allow the study of the Hadley cell evolution through analysis of its surface branch.**

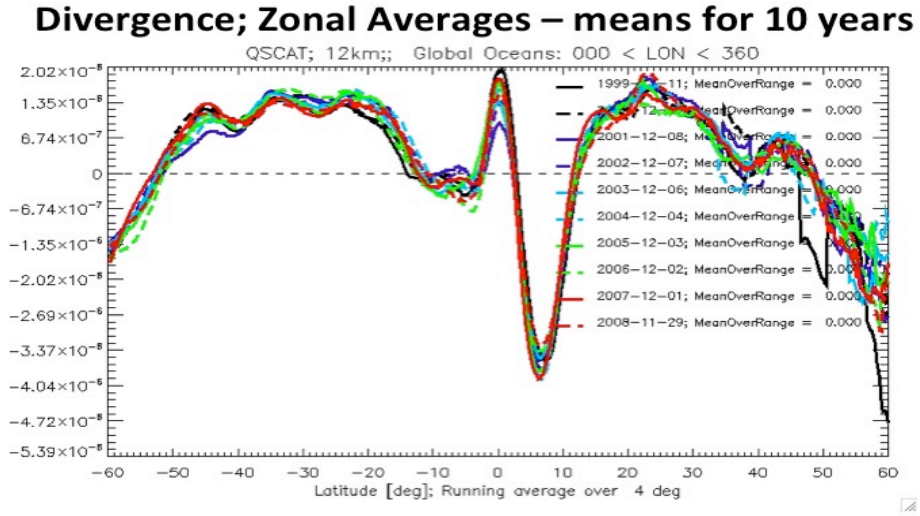
Questions we ask …

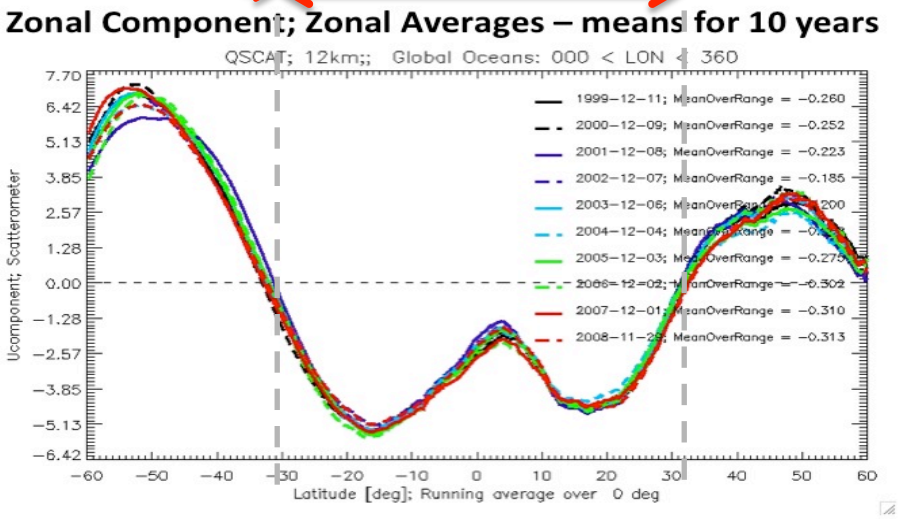
- How to define the extent and intensity of the Hadley cell from scatterometer observations?
- How are the signatures of the Hadley cell changing during the 10-year QuikSCAT record?
- Looking beyond the QuikSCAT era:
  - The launches of ASCAT on METOP in 2006 and the ISRO's OceanSAT-2 in 2010 will assure the continuation of the climate data record of near-surface winds over the oceans.
  - Before we combine the signals from the different instruments we should:
    - Analyse them and understand whether they are consistent with each other
    - Determine the sources for disagreements if such are found
  - Failure to do so would lead to creating artificial cycles and trends in the Hadley cell structure
- How will RapidScat help!

Approach

- Use the observations from QuikSCAT and ASCAT. **Compute statistics from time composites (1-year and 3-month running averages, offset by 2 weeks**.)
- Determine the **extent of the Hadley cell** as defined by the subtropical zero-crossing of the zonally-averaged zonal wind component (the separation between the midlatitude westerlies and the easterly winds in the tropics).
- Determine the **circulation strength** as defined by the area of divergence/conv.







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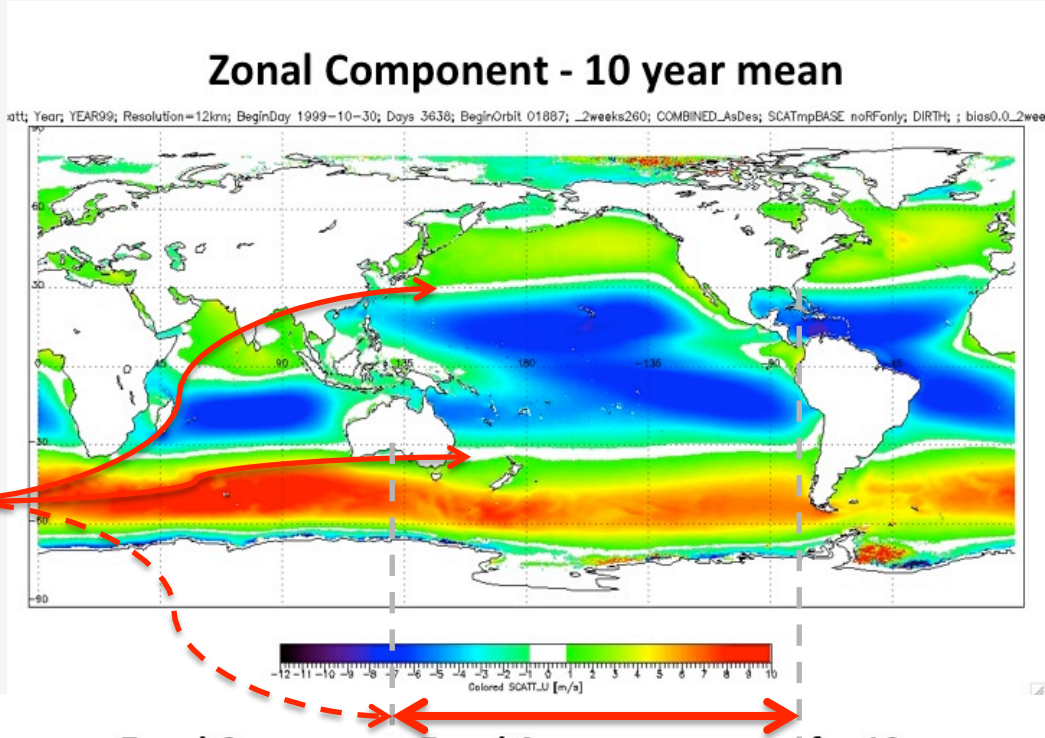
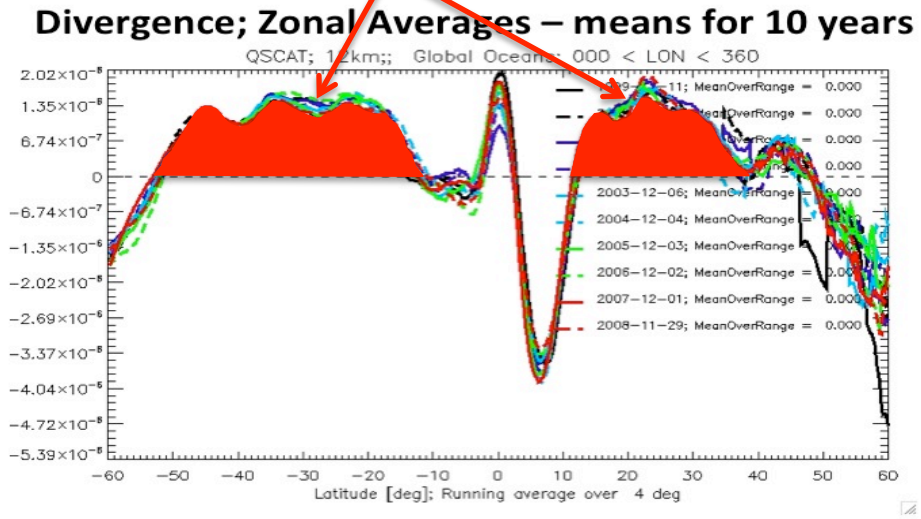
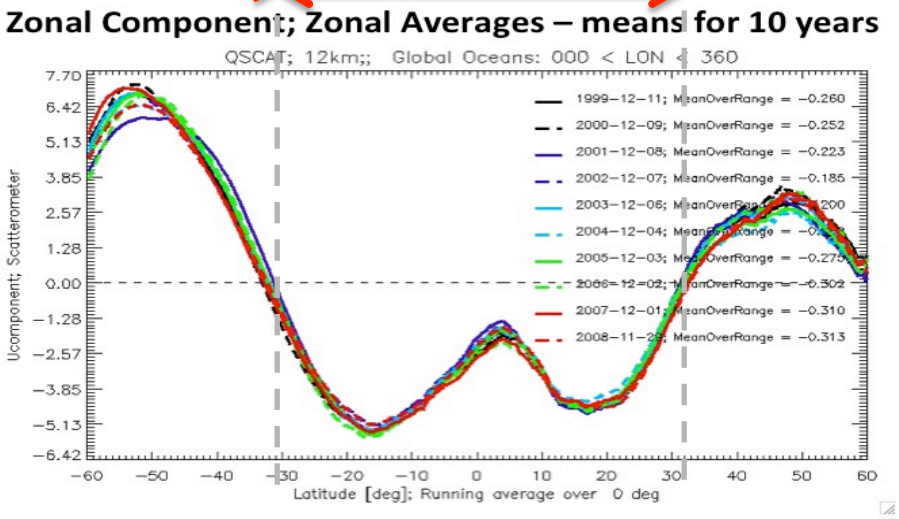
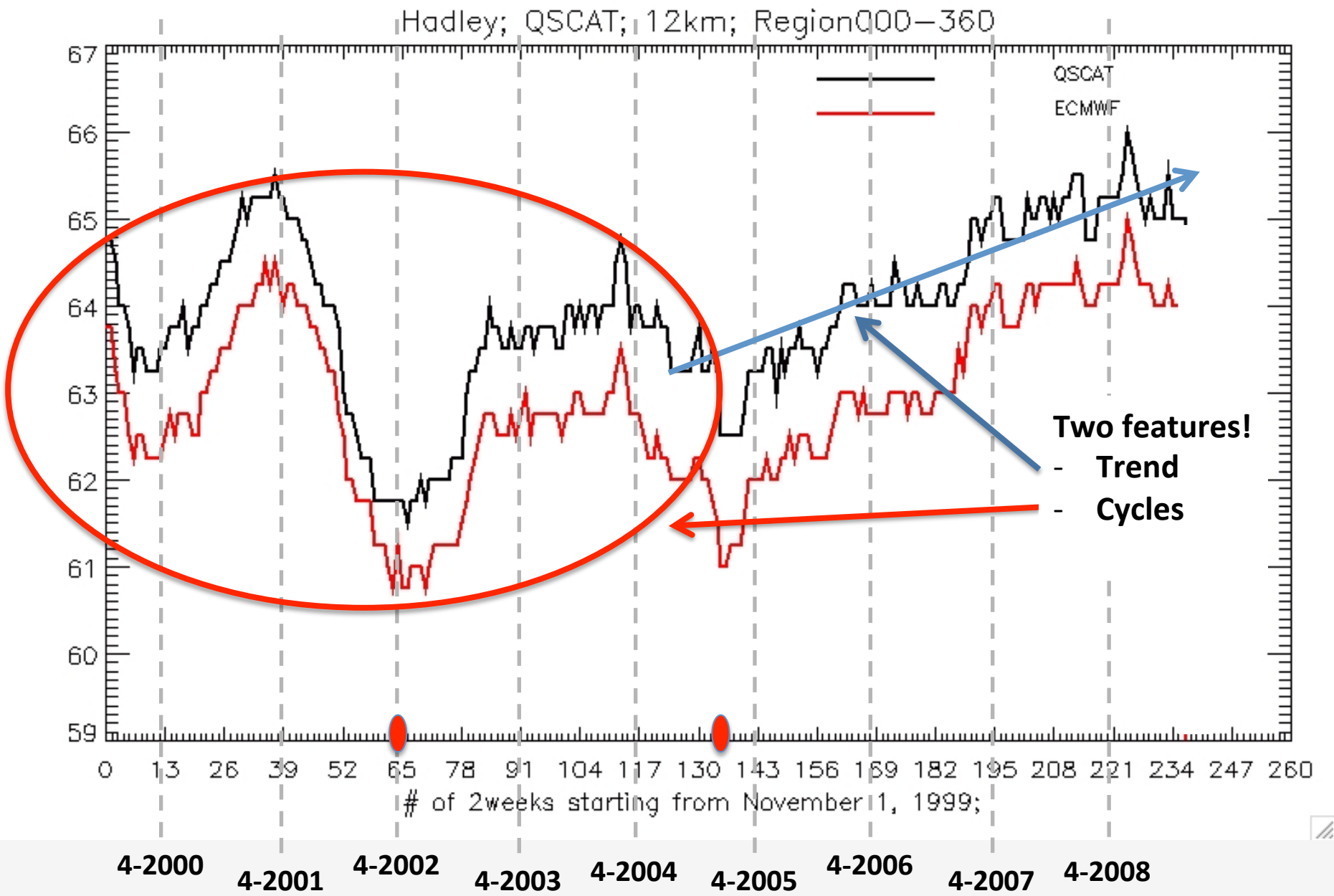


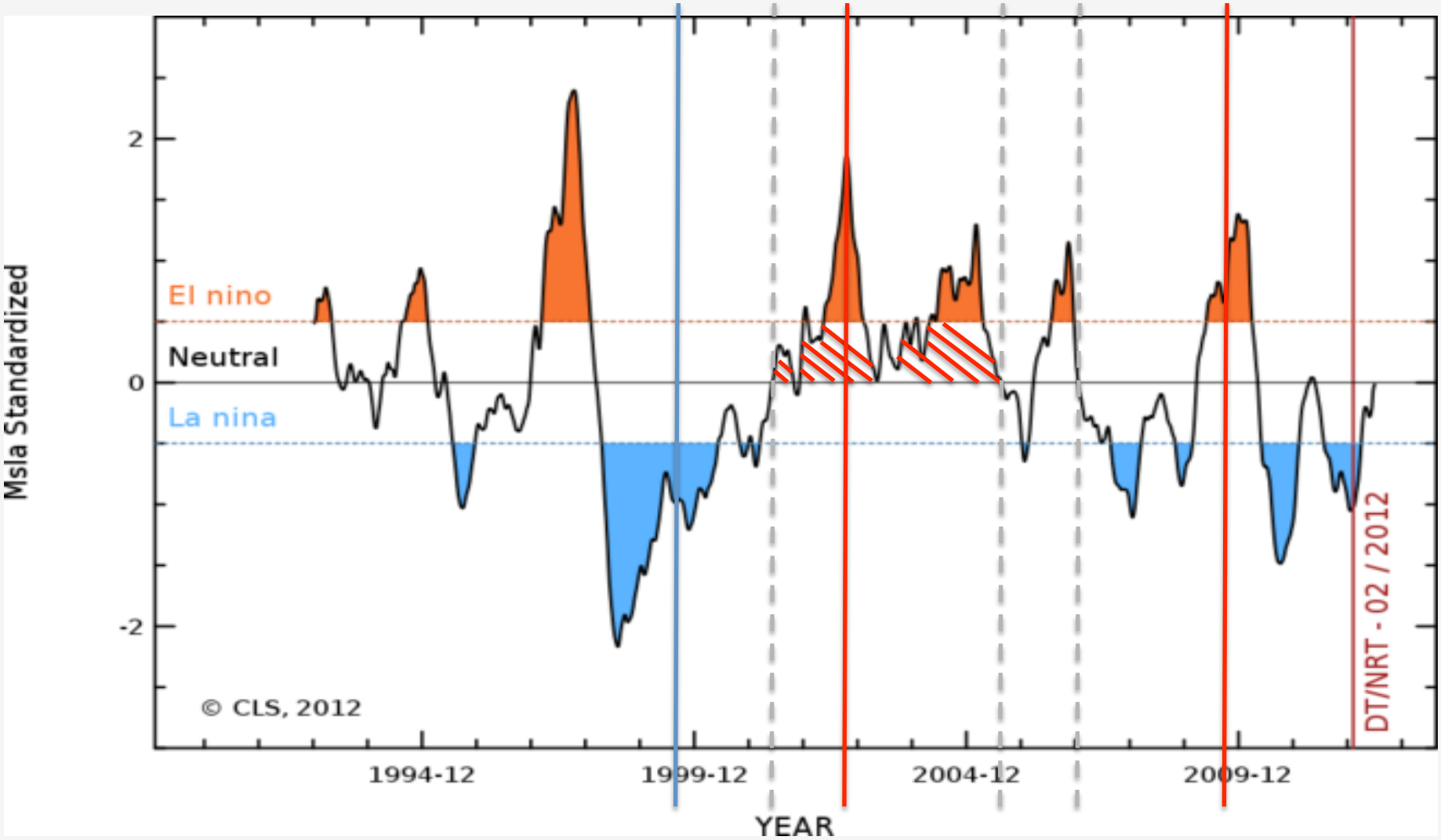




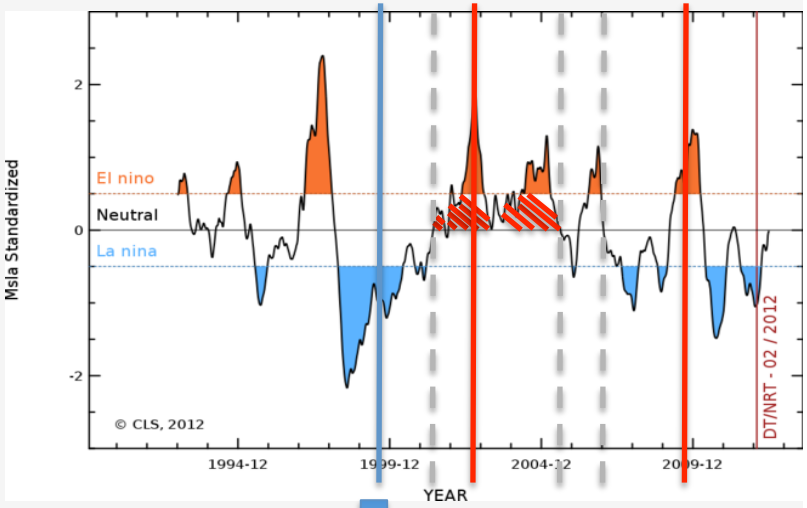
Width of Hadley as determined from:
Global data; 1-year averages; The zero-crossing of U

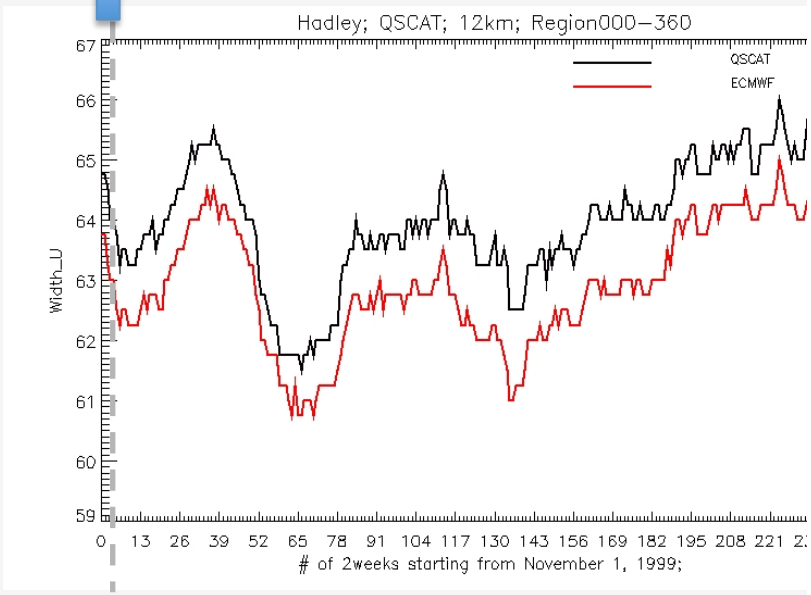


The Oscillation – maybe related to La Nina/ El Nino



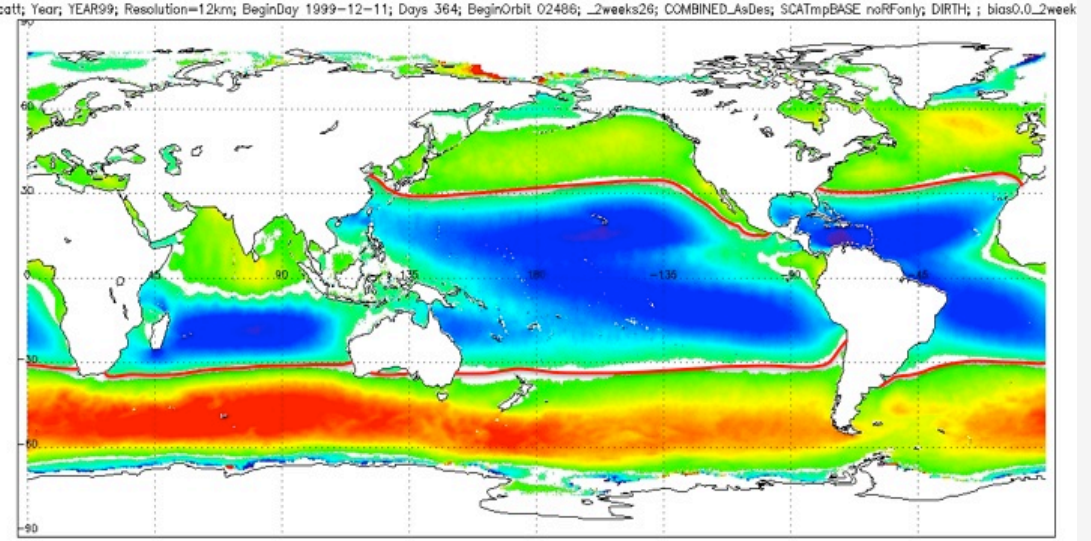
La Nina

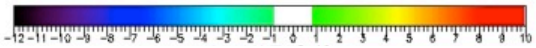


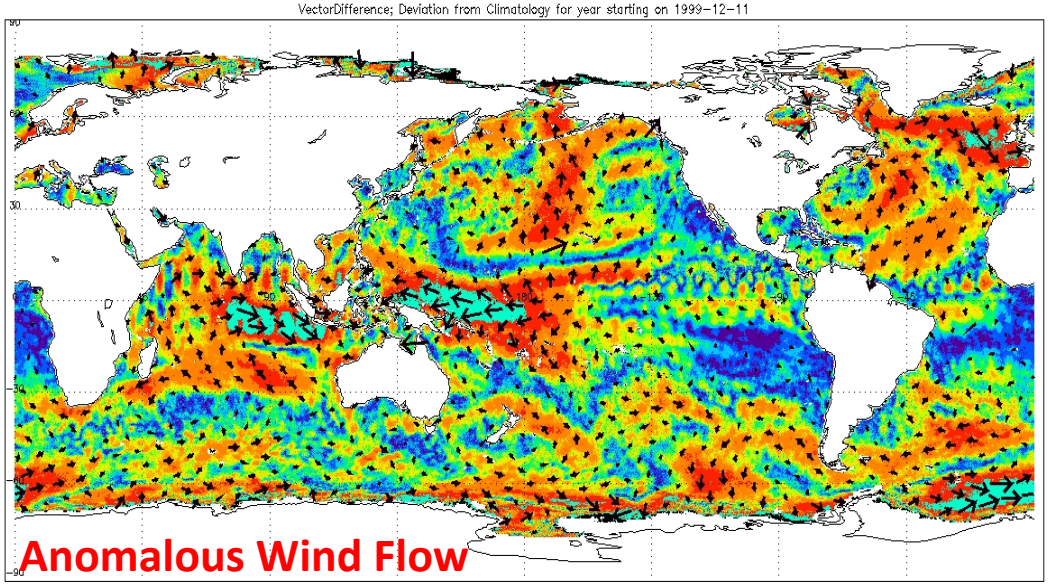


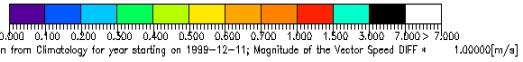
12-1999

Zonal Component – Year Beginning on 12-11-1999

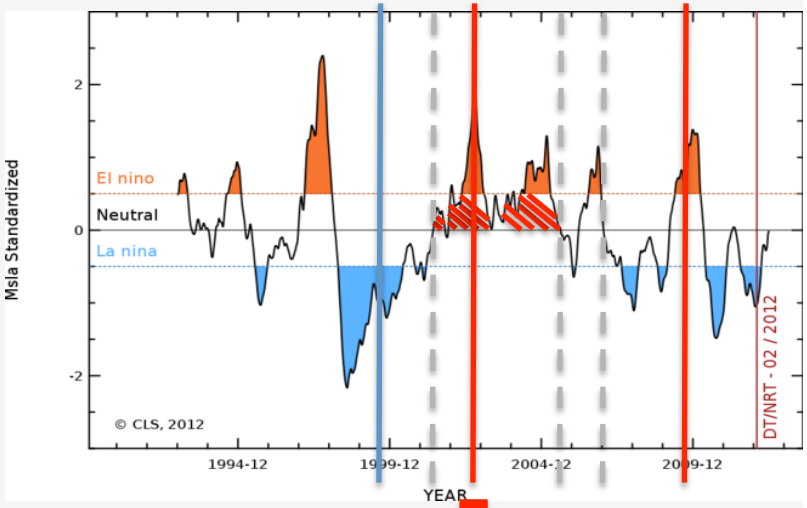




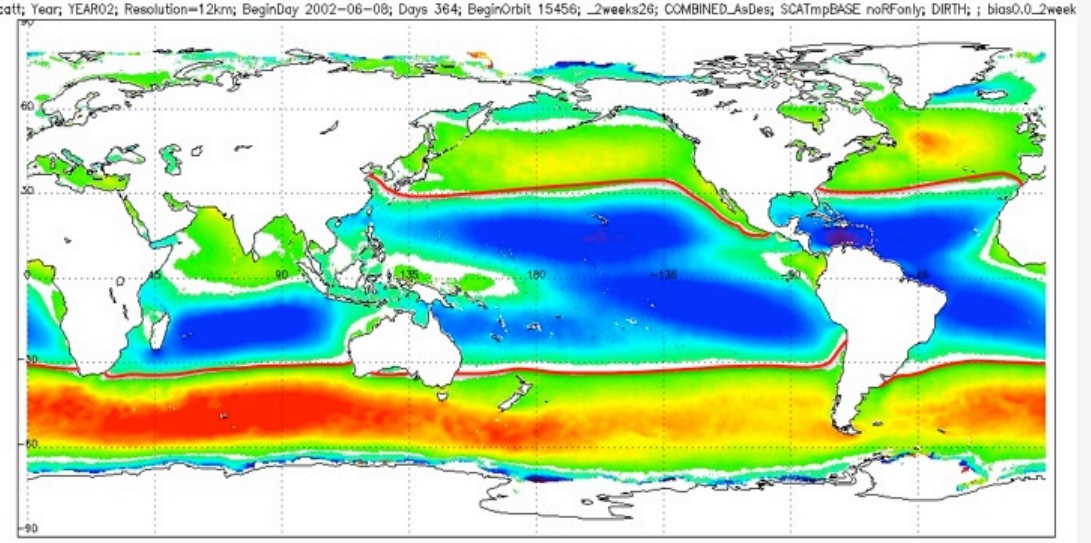


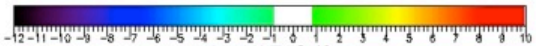


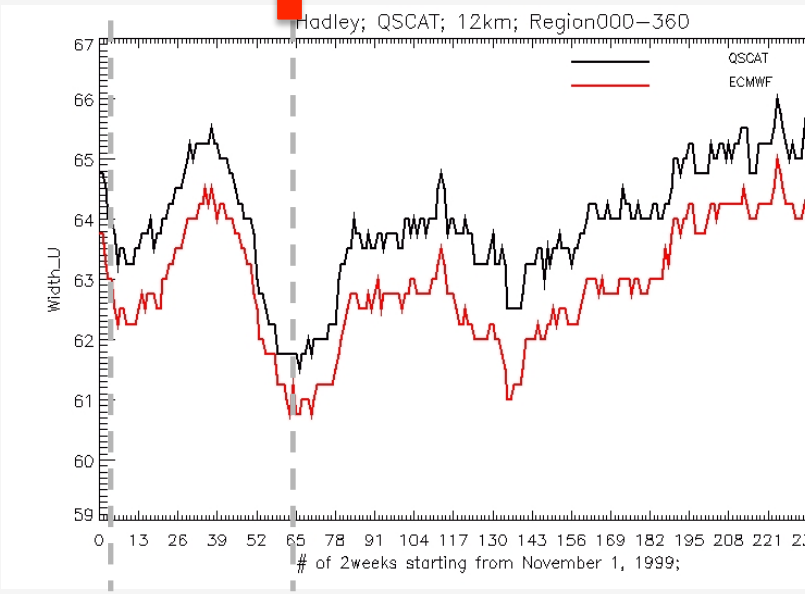
El Nino



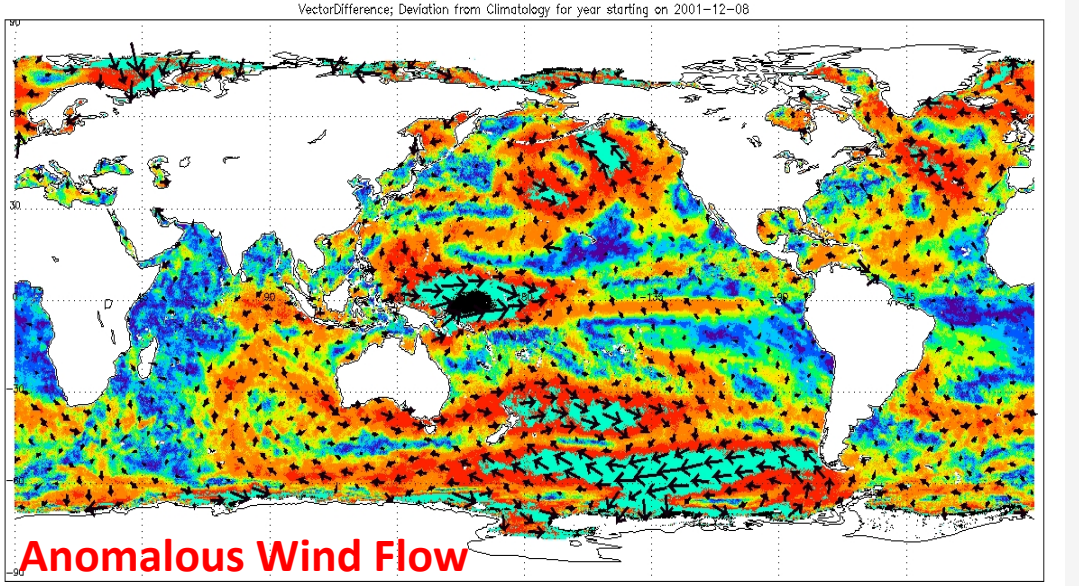
Zonal Component – Year Beginning on 06-08-2002



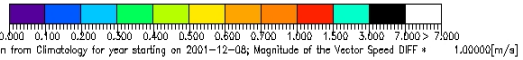




12-1999 **4-2002**

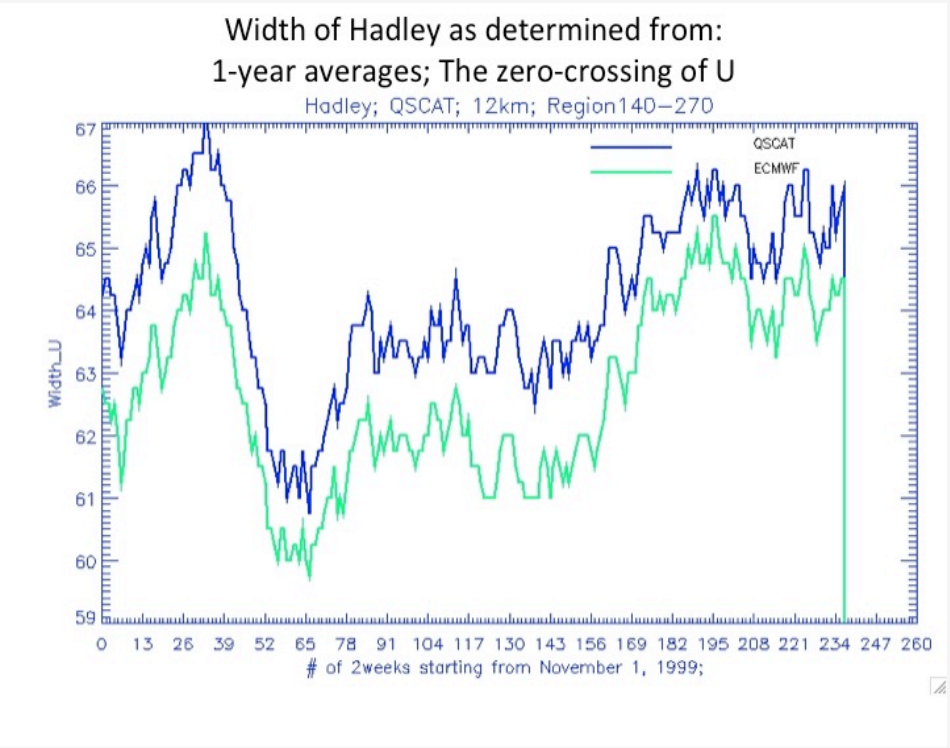


Anomalous Wind Flow

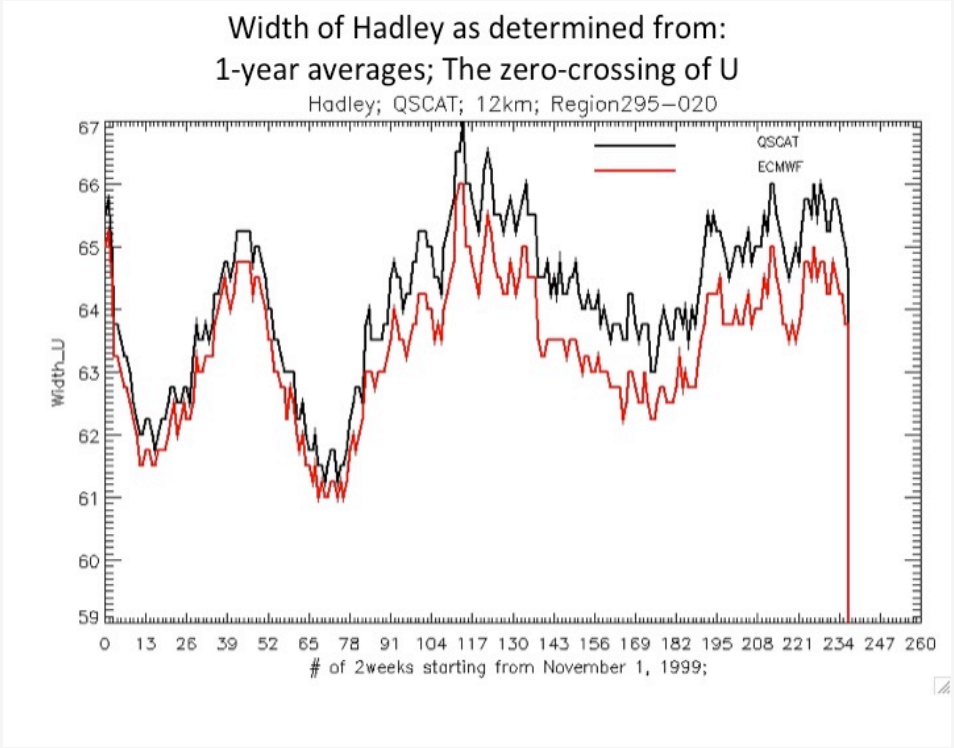


Geographical Variability

Pacific Basin



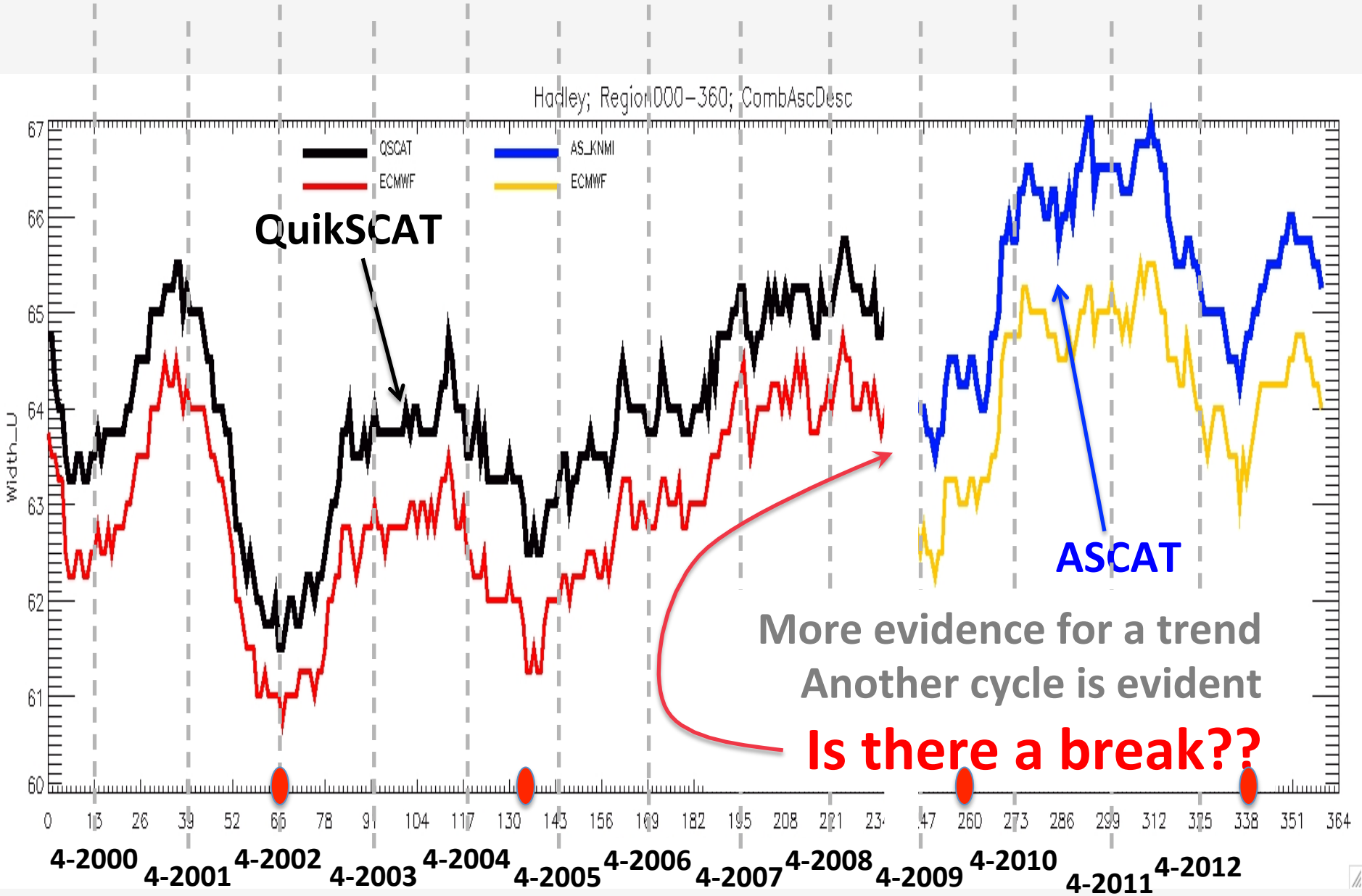
Atlantic Basin



It appears that the behavior has a geographical variability with:

- More pronounced trend in the Pacific
- More pronounced oscillations in the Atlantic

Looking beyond QuikSCAT



More evidence for a trend
Another cycle is evident

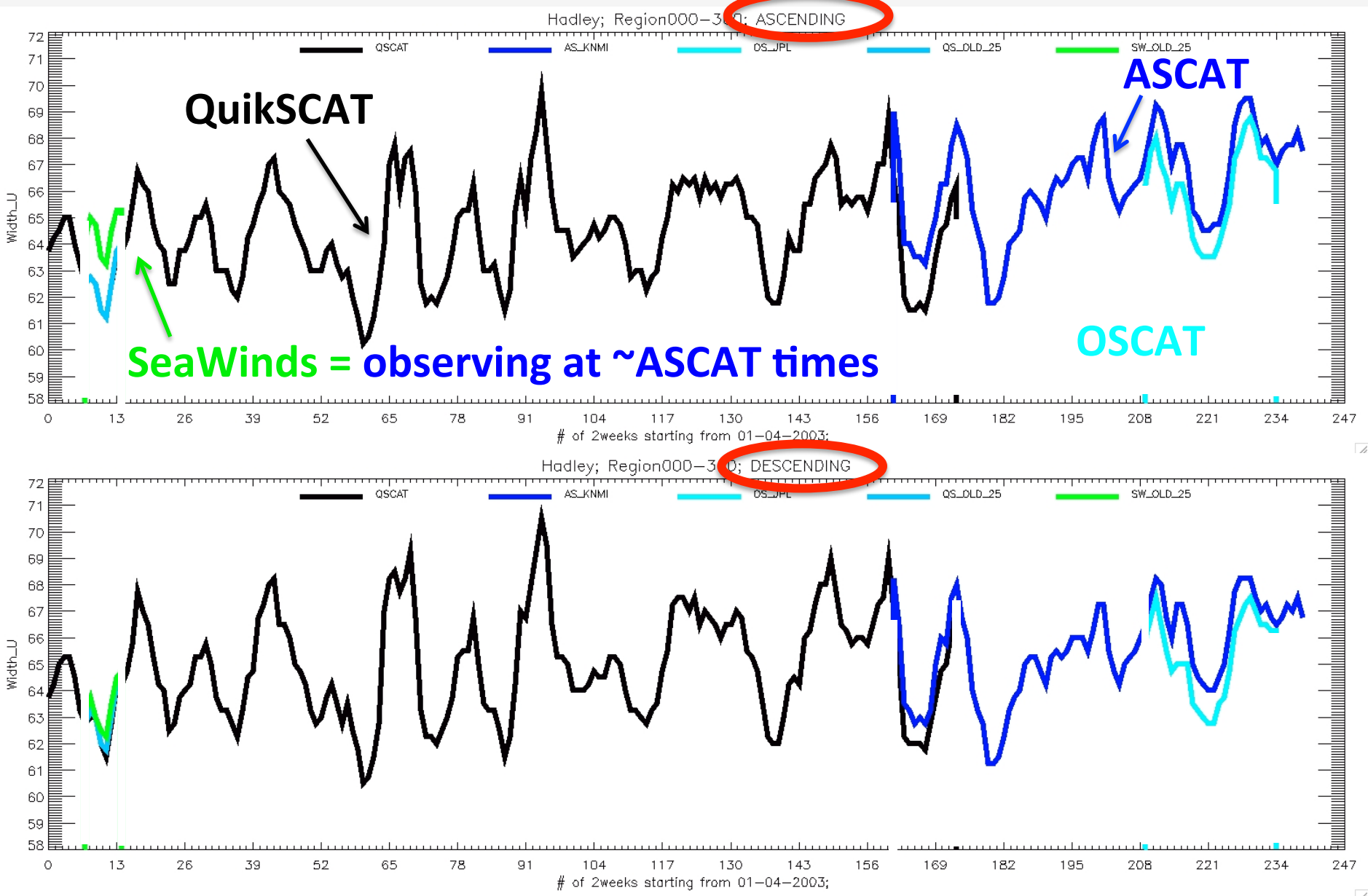
Is there a break??

In summary ….

- There is a discontinuity the Hadley cell width record when using different satellites !!
- Diurnal variability might be the reason.
  - Tandem Missions – what do they show
  - RapidSCAT will help attribute the differences

Tandem Missions (using running 3-month averages)

Breaks in the Hadley width (by U) when using different satellites !!



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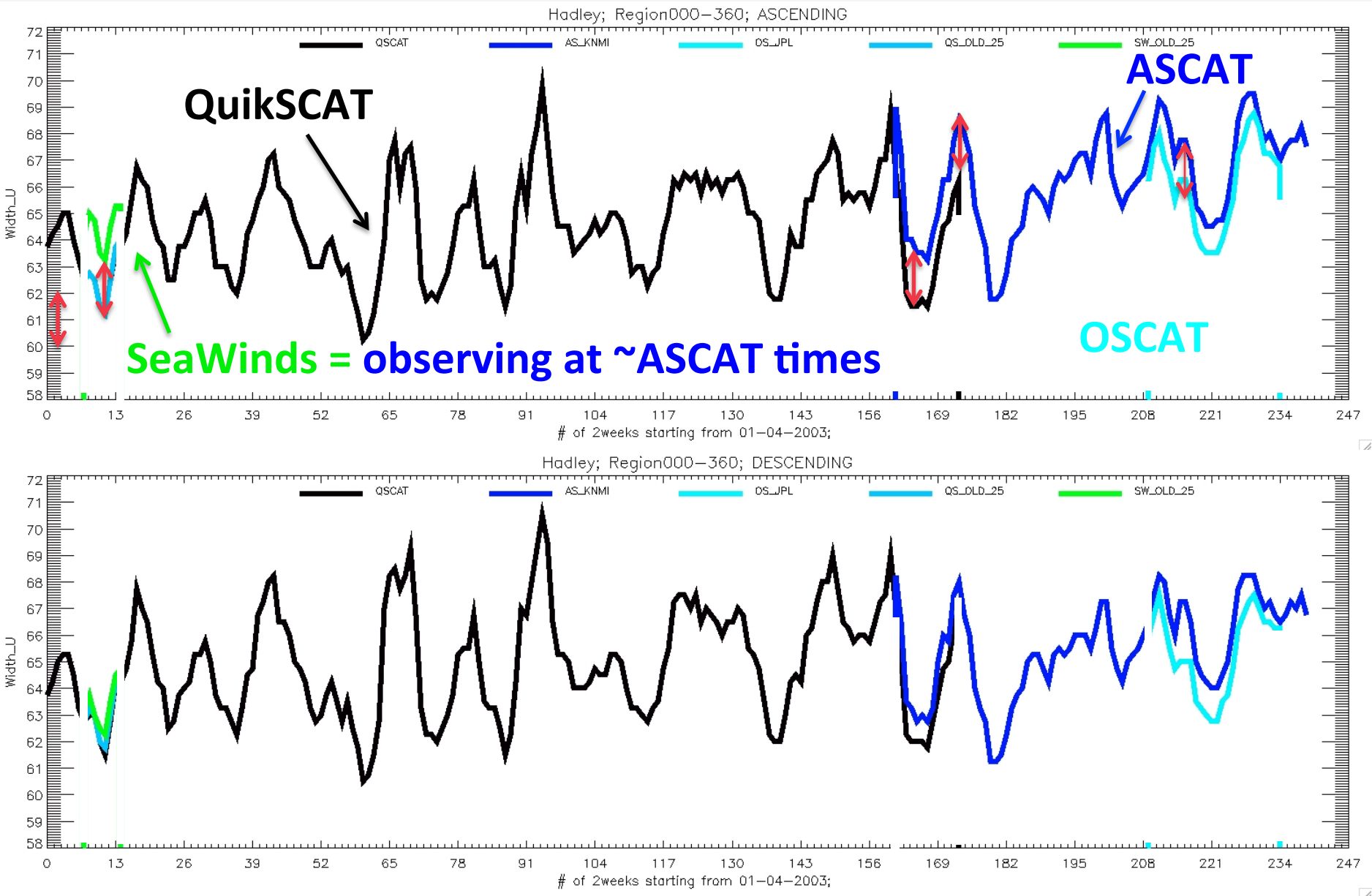

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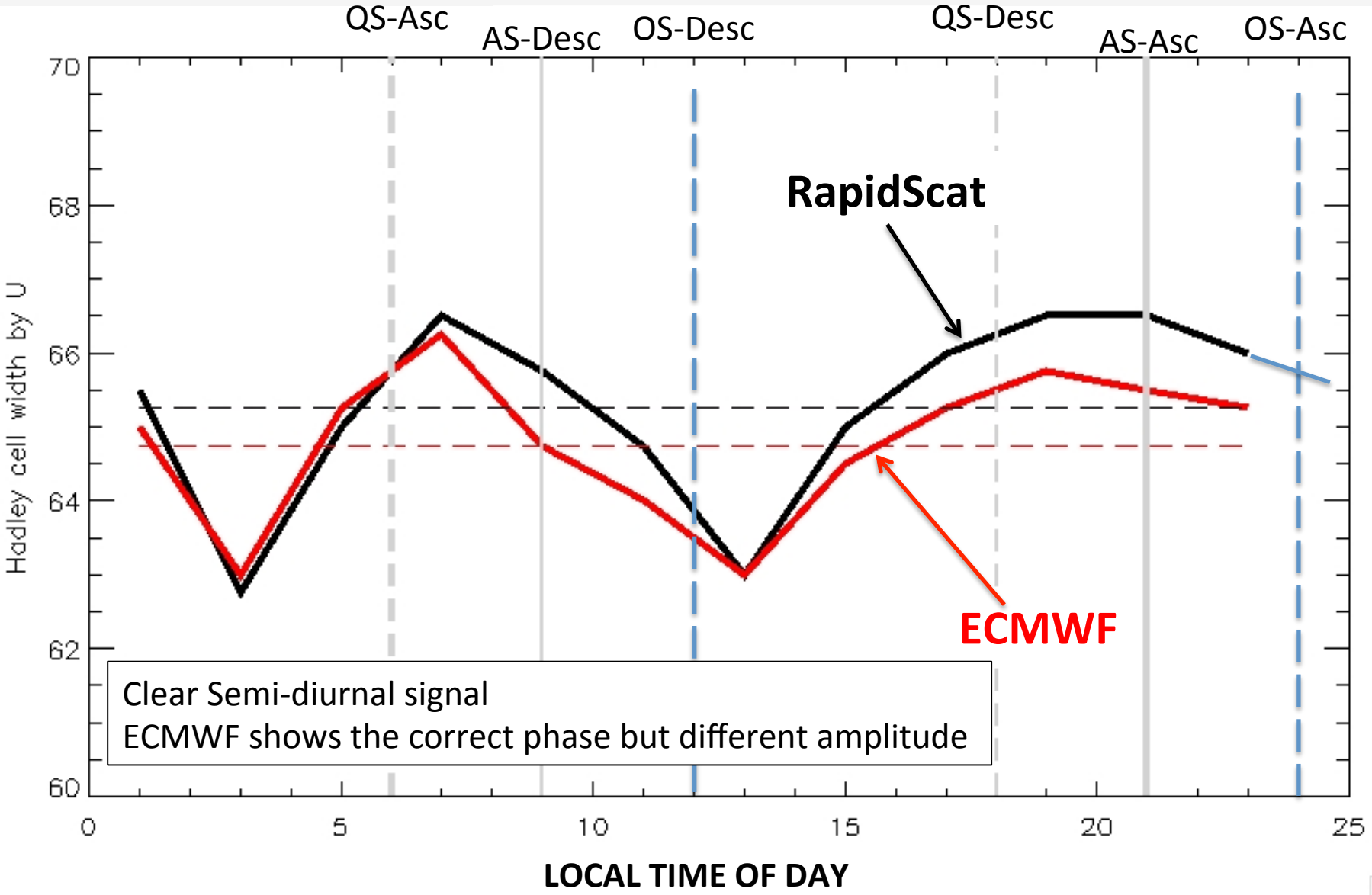
RapidScat
Hadley Width by the Zonal Wind U



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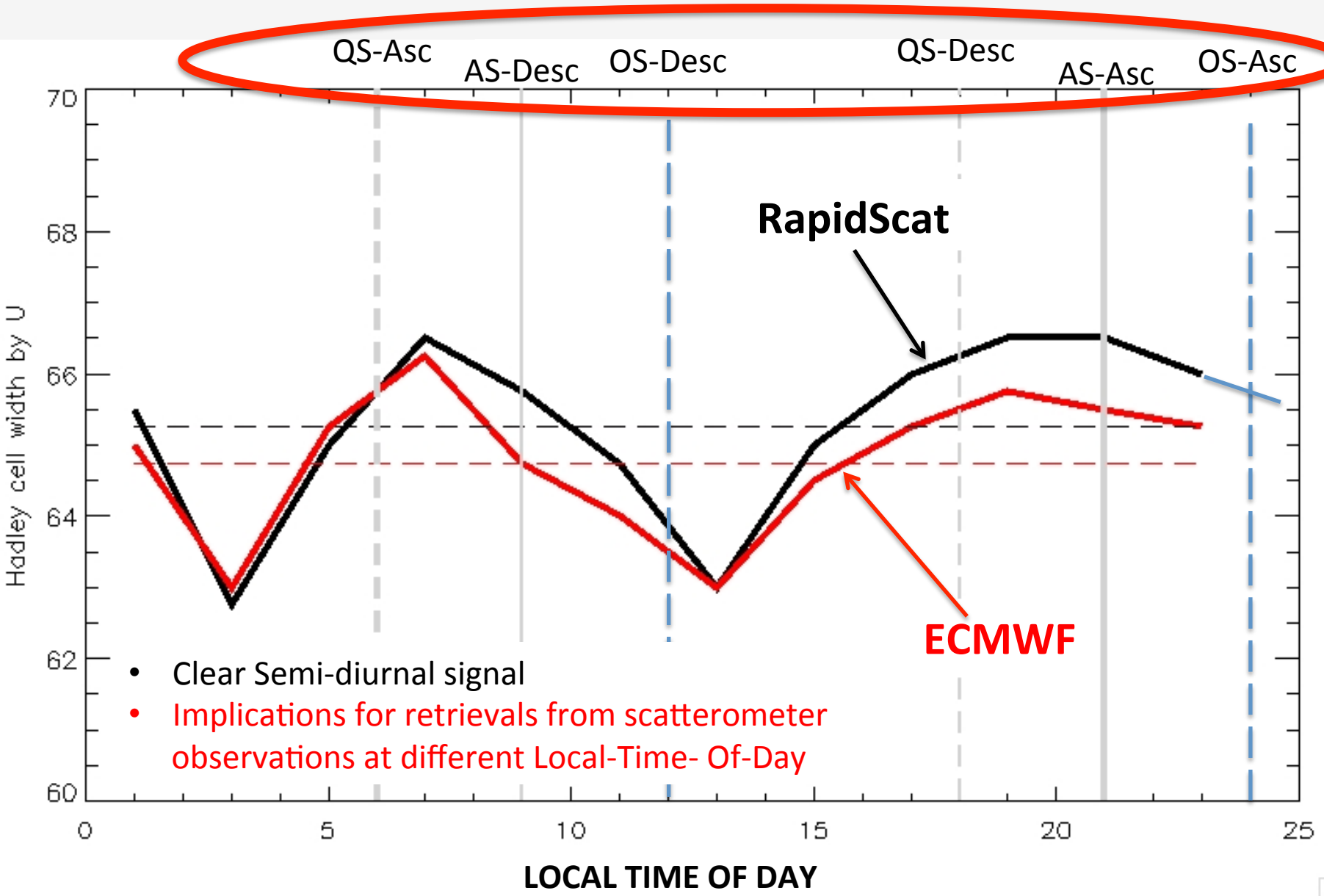
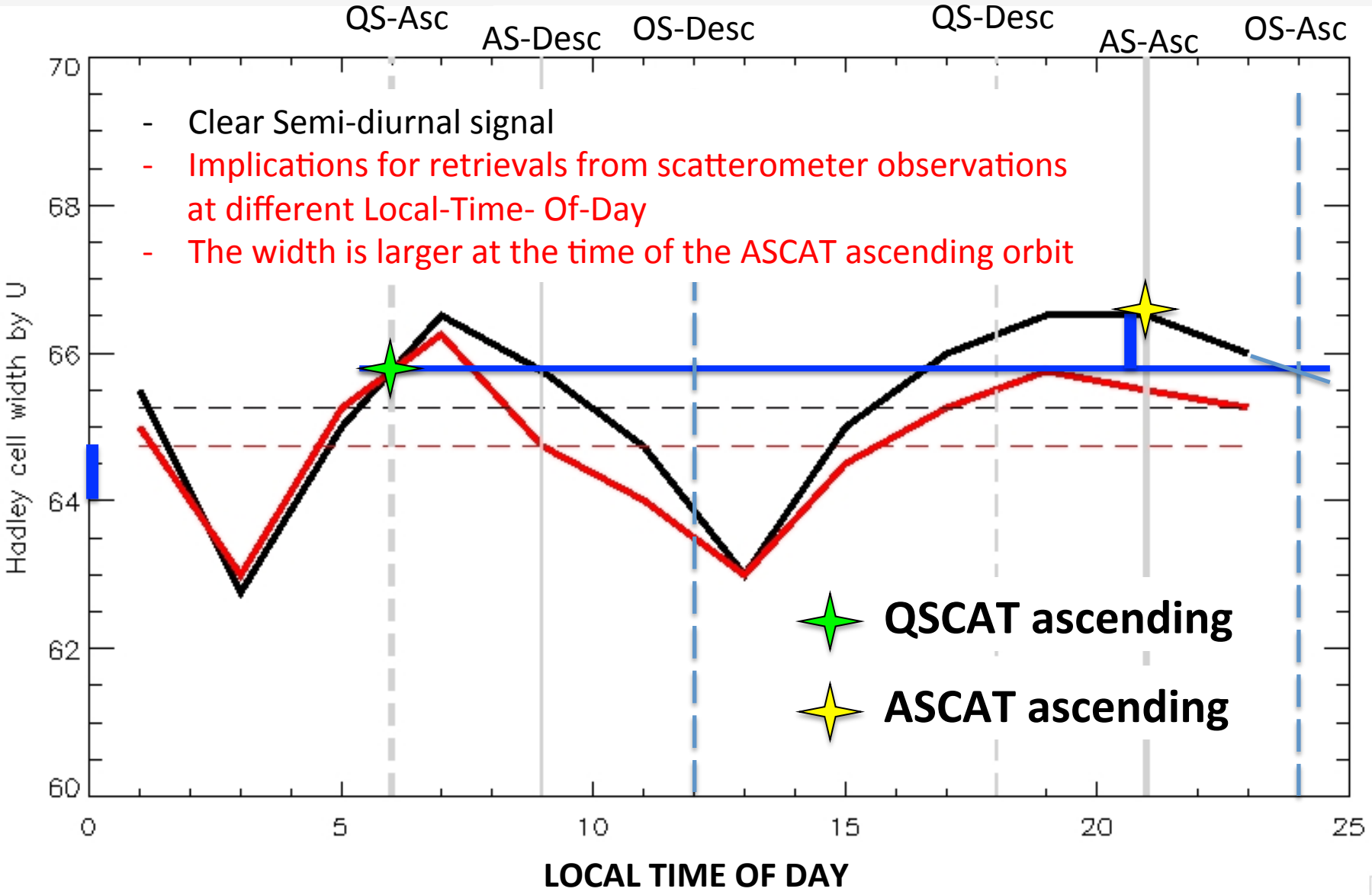


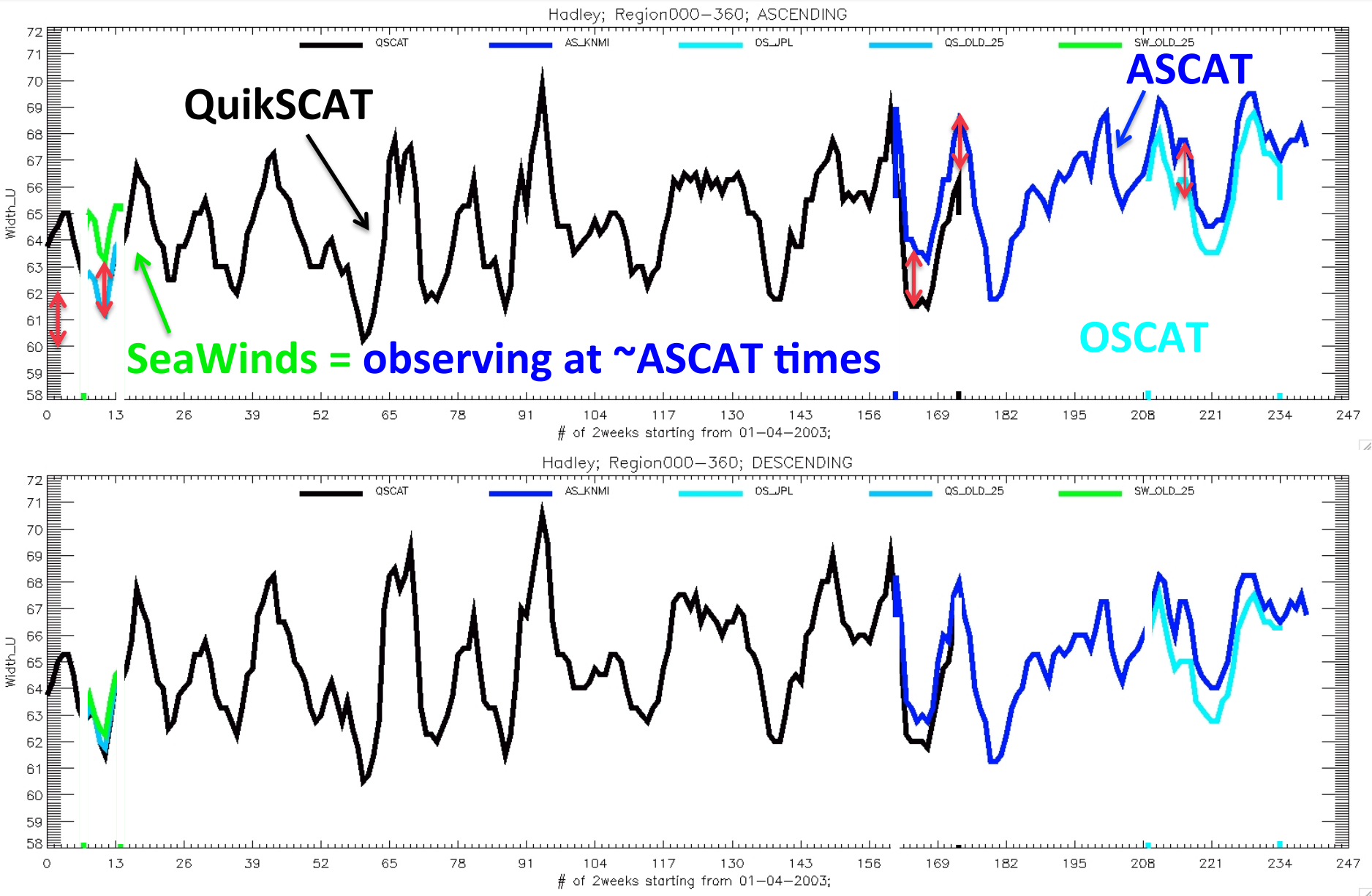
- Clear Semi-diurnal signal
- Implications for retrievals from scatterometer observations at different Local-Time- Of-Day

Hadley Width by U



Tandem Missions (using running 3-month averages)

Breaks in the Hadley width (by U) when using different satellites !!



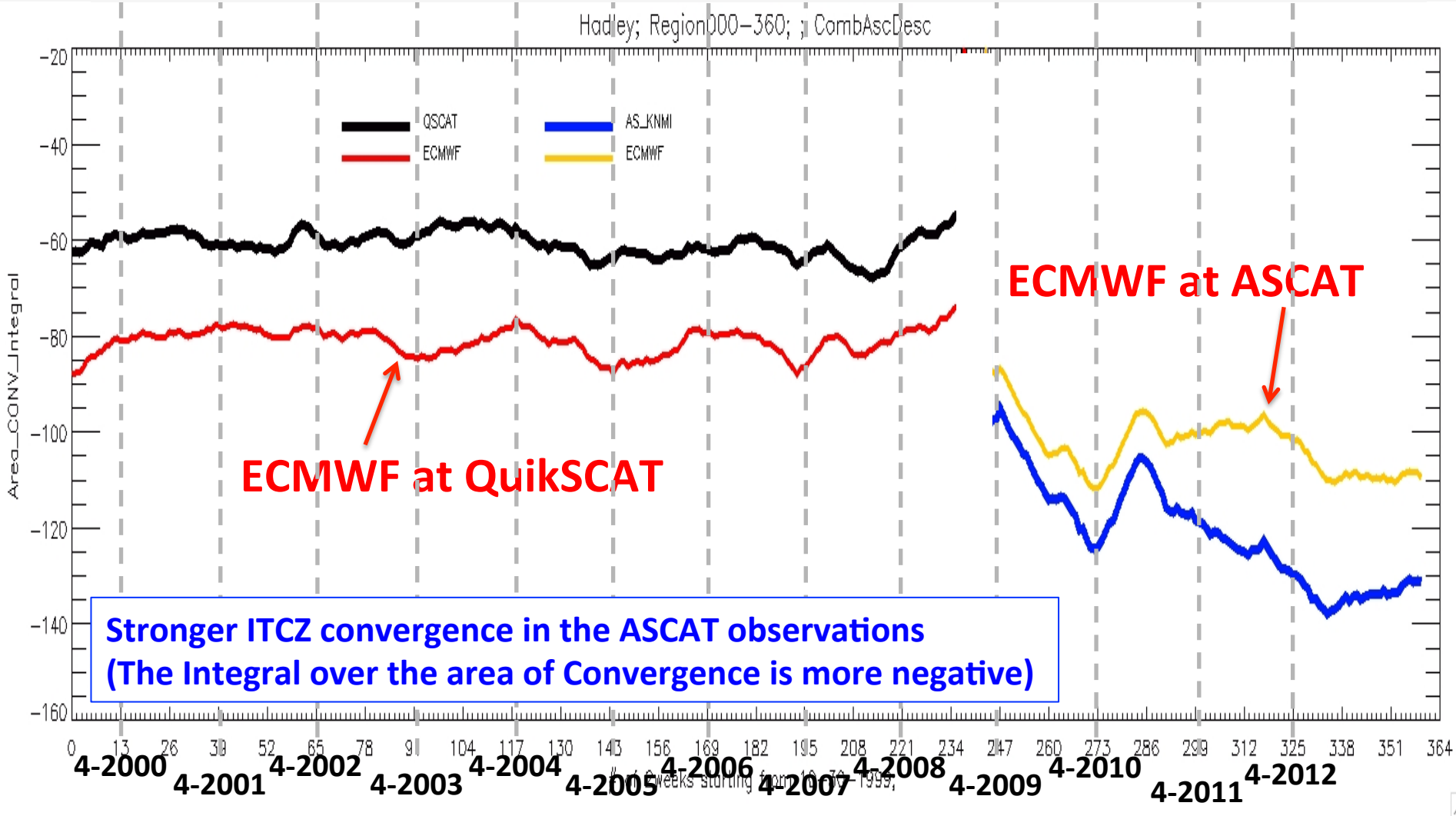
Diurnal Signals in Convergence

- How does the ITCZ convergence change when using observations from different scatterometers?
- Could we use the models to infer the Diurnal Signals in the Hadley cell?
- What is the diurnal signal in RapidScat observations

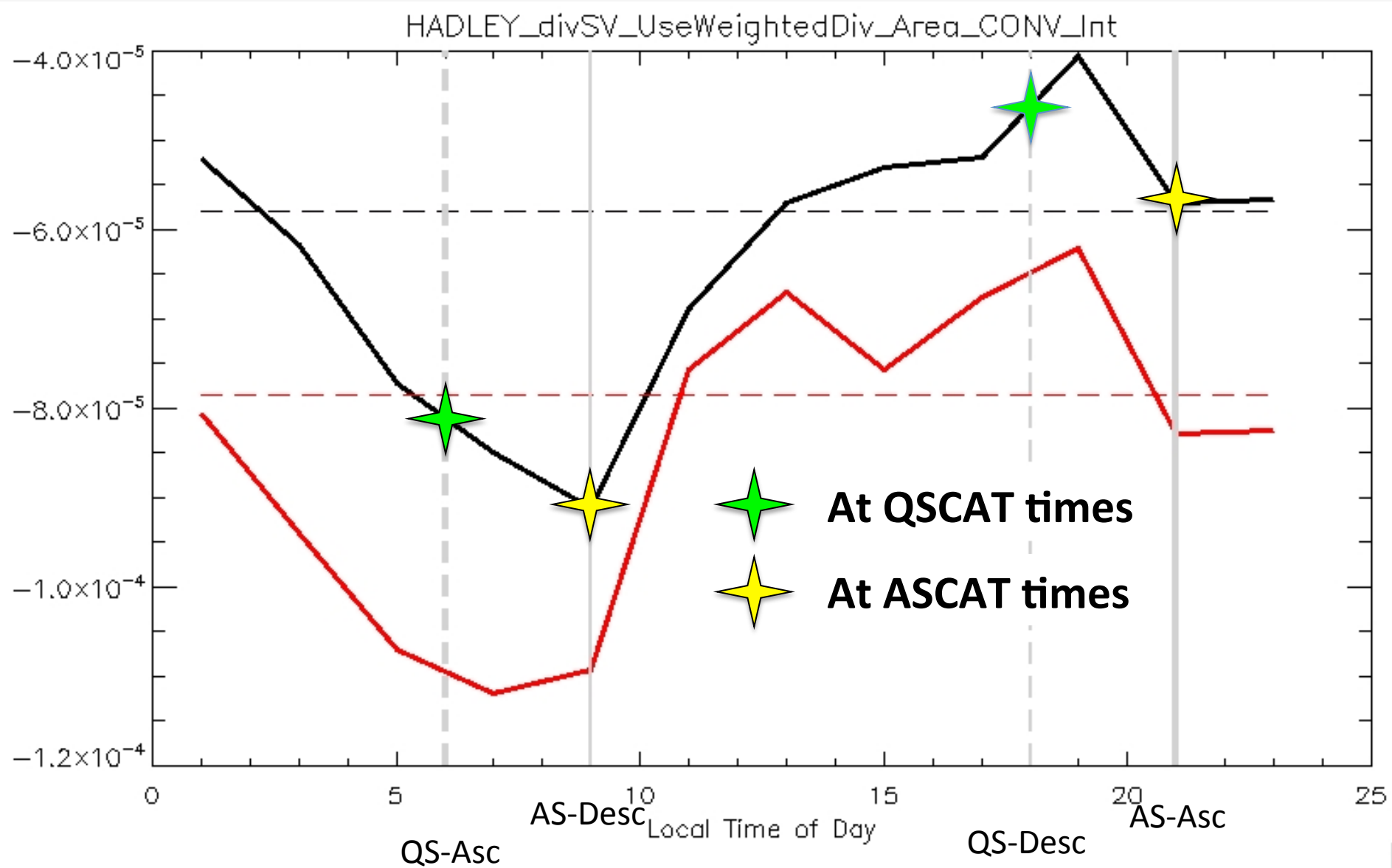
Convergence (area integral) – is there a break?

Is ECMWF capturing the signal correctly ?

- ECMWF shows no significant change between the QuikSCAT and the ASCAT periods
- **Scatteromter observations show a change – why the difference from ECMWF??**

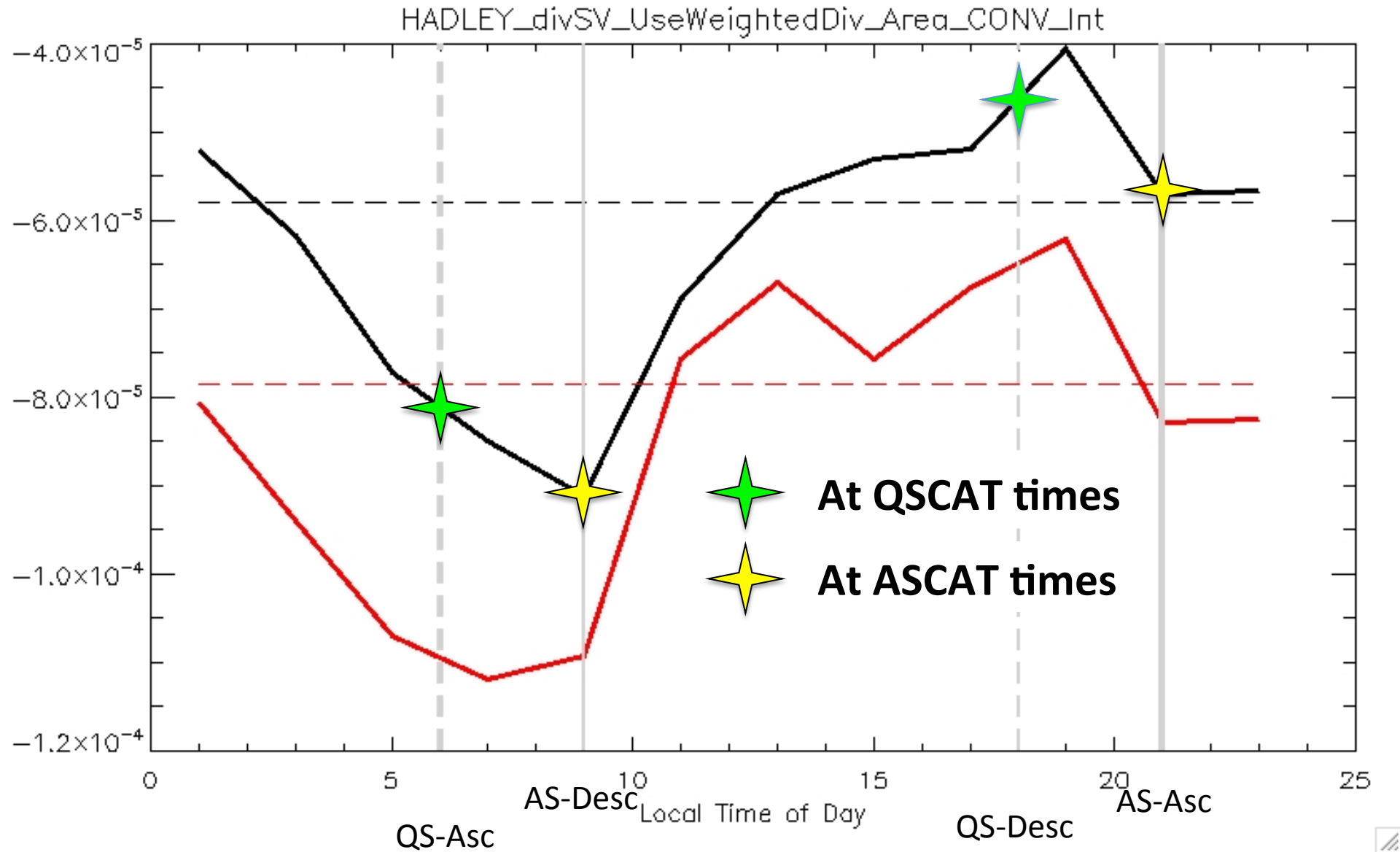


Hadley Convergence (Integral)



Hadley Convergence (Integral)

Stronger ITCZ convergence in the ASCAT observations
(The Integral over the area of Convergence is more negative)



Summary

- **We use scatterometer surface wind observations to detect the extent of the Hadley cell and to study its characteristics over the last 14 years.**
- **QuikSCAT period:**
  - **Two distinct cycles in the Hadley cell width during the first half of the QuikSCAT record**
    - **They are likely a reflection of the modulation of the Hadley cell by the La Nina(1999)/El Nino (2002) events that dominated this period.**
  - **A steady increase in the width during the later part of the QuikSCAT record**
  - **Different evolution of the Pacific Hadley cell versus that in the Atlantic.**
  - Analyzing the time series of 3-month running averages **reveals the seasonal variations of the Hadley cell.**
- **ASCAT period: Extending the record to include the ASCAT period shows more evidence for a trend and reveals another cycle (related to the developing El Nino??).**
- **There is a discontinuity between the two records. Need to understand why.**
  - **Diurnal variability might be the reason. RapidSCAT will help address this issue**
- **ECMWF analysis of the Hadley cell structure and evolution show differences from the scatterometer-based ones. These differences vary both in space and in time!**

Summary (cont.): RapidScat

- We found breaks in the Hadley width (as determined from the zonal wind U) when using different satellites !!
- We suspected the cause might be an unaccounted for diurnal variability
- To investigate this diurnal signal we looked now at:
  - Tandem Missions
  - RapidScat observations !!
- Our analysis show that:
  - Tandem mission analyses seem to support the significance of the diurnal signal
  - RapidScat analyses
    - revealed that there is a significant variability in the Hadley Cell width, with a clear semidiurnal signal
    - provide strong evidence that the Hadley cell is wider during the ASCAT observing times than it is during the QuikScat observing times
    - This supports our theory that diurnal variability might be the cause for previously found discrepancies between QSCAT and ASCAT observations and supports our earlier findings

BACKUP